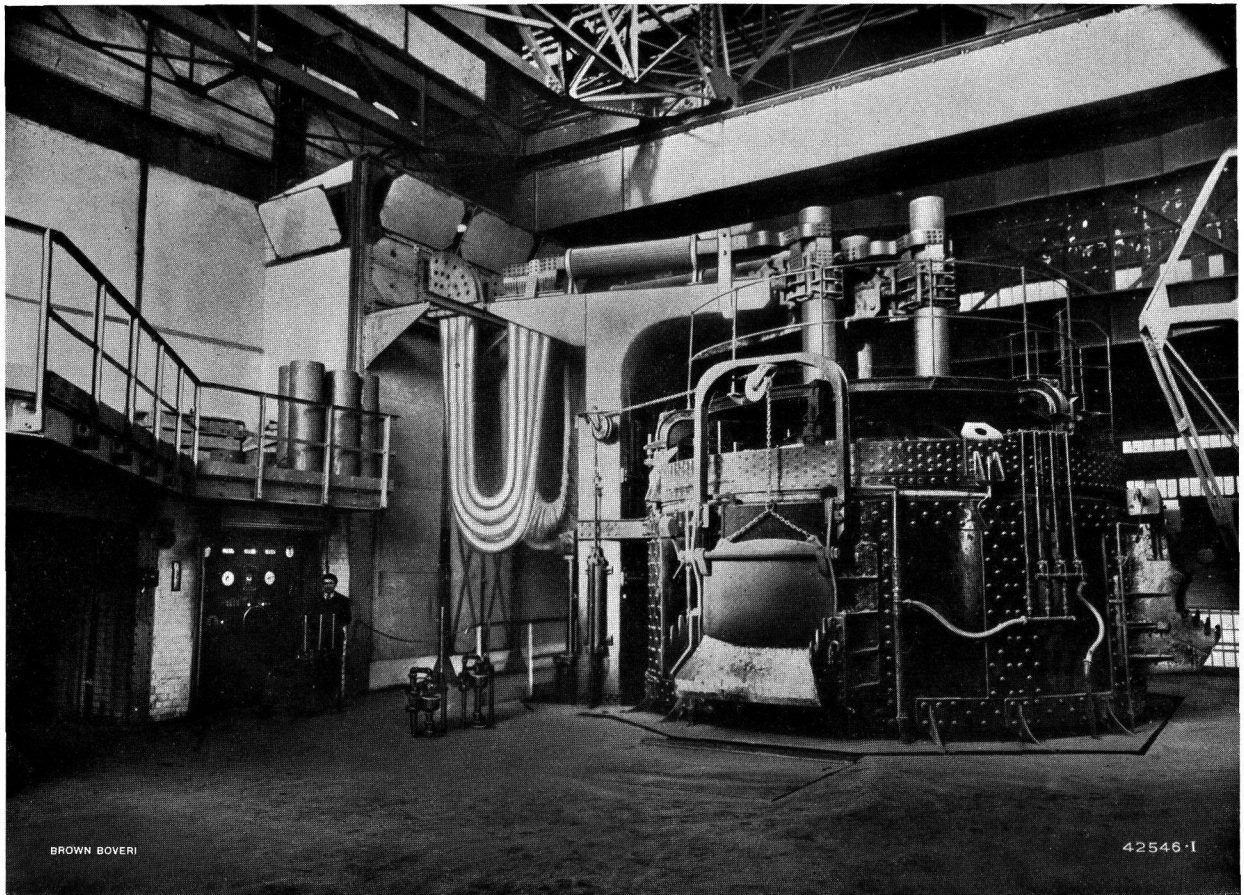


# THE BROWN BOVERI REVIEW

EDITED BY BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)



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# THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

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## THE BROWN BOVERI REMOTE-CONTROL SYSTEM.

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### I. INTRODUCTION.

THE linking-up of large power stations supplying extensive distribution networks, so generally practiced, to-day, created a demand for contrivances for signal transmission, remote metering and remote control. Considerable progress has been made in such systems, during recent years. Not only have the existing systems been improved upon, but fundamentally new methods have been introduced. The requirements imposed upon the remote control systems have also been considerably increased. To-day one expects the system and the apparatus to fulfil the requirements of not only heavy-current engineering, but also those of communication engineering. Brown Boveri have contributed their share towards solving this none-too-easy problem and, as a result of many years' research work, have developed systems which meet the highest service requirements. A brief description of the said systems is given in the following paragraphs.

### II. GENERAL PRINCIPLES OF REMOTE CONTROL.

The remote control equipment is used not only for the control of heavy-current apparatus at distant points, but also for signalling back that the control operation has been carried out and often, also, for announcing other occurrences in the plant under supervision, such as the acting of alarm signals and the tripping of protective relays. In principle, there is no difference between control and return signals. In both cases it is the duty of the remote-switching system, by closing a circuit at the emitting end, to select a corresponding circuit at the receiving end from a number of such circuits available. As a rule, there is only one pair of pilot wires available to connect the sending and receiving stations. Systems which require several pilot lines are prohibitive in cost. The process of transmission, the fundamental working principle of which is most commonly applied, consists of automatic switching over of the pilot line from one sender-receiver set to the next.

Rotating selectors are generally used, as a change-over device, which move forward synchronously, step by step. Fig. 1 shows the fundamental connections of such a selector device. The selector moves

only when a control order or return signal is to be transmitted. The use of the rotating selector is almost universal in practice, although the same object can be attained by other methods, as, for instance, with

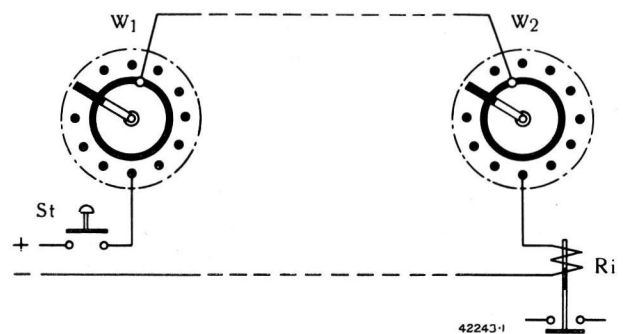


Fig. 1. — Fundamental design of a remote-control equipment with rotating selectors built to the single impulse principle.

R. Individual receiving relay.  
St. Control switch.

W<sub>1</sub>. Selector of emitting station.  
W<sub>2</sub>. Selector of receiving station.

the help of a chain of relays. From the beginning, Brown Boveri has based their methods of construction on the rotating-selector principle, a choice which subsequent research has proved to be correct. Fig. 2 shows an apparatus with moving selector, built in the year 1925.

The simple process of connecting the sending and receiving circuits, which are related, over the common pilot lines, had to be perfected when it became necessary to make use of

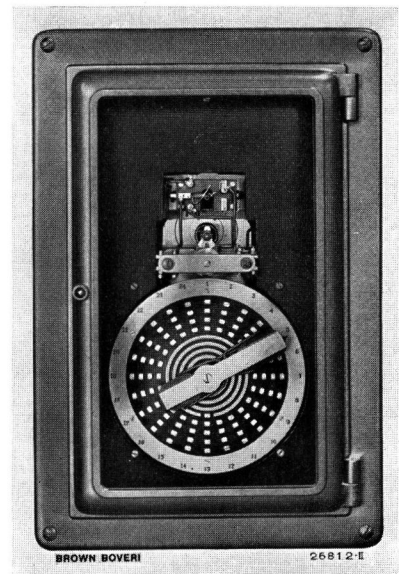


Fig. 2. — Remote-control apparatus with rotating selector, moving round when an operation is to take place, built in 1925.

pilot leads which were subject to external troubles caused by induction phenomena. If a current, which has not been generated at the sending end appears in the pilot line, no gear should be used which is based on the principle that a single impulse suffices to actuate a controlling or signalling apparatus at the receiving end. The disturbances caused by induction from external sources can only be eliminated by introducing an arrangement by which the operation of the control and signalling apparatus require a complete series of impulses and not just one impulse. In so doing, the number and duration of individual impulses as well as the intermediate pauses between them are automatically checked. Thus, if the series of impulses coming in show any irregularity, they remain ineffective on the apparatus. This improved arrangement of the remote-control system can also be carried out while retaining the funda-

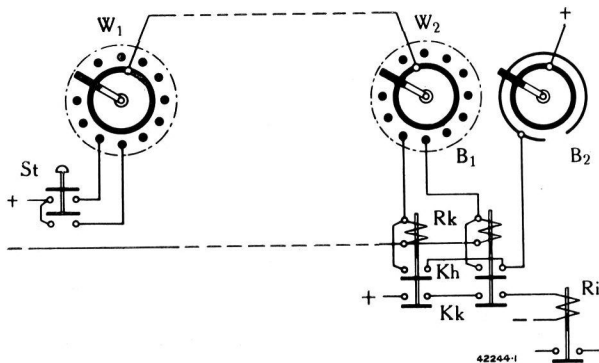


Fig. 3. — Fundamental design of a remote-control equipment built to the coded impulse principle with a pair of rotating selectors.

- |   |   |
|---|---|
| B <sub>1</sub> . Selector track for excitation of the combination relays.           | K <sub>k</sub> . Combination contacts.          |
| B <sub>2</sub> . Selector track for the holding circuits of the combination relays. | R <sub>i</sub> . Individual receiver relay.     |
| K <sub>h</sub> . Holding contacts.  | R <sub>k</sub> . Combination relay.             |
|   | St. Control relay.                              |
|   | W <sub>1</sub> . Selector in emitting station.  |
|   | W <sub>2</sub> . Selector in receiving station. |

mental principle of remote change-over switching through the agency of a rotating selector, as shown in Fig. 3.

As already mentioned, the remote-control equipment is used to-day for various purposes, so that the design must cover a very wide field. The simplest case is when a small automatically-controlled plant is to be controlled and supervised from the next attended station. As a rule, the pilot or control line is formed of one pair of long distance telephone cable wires, the said cable belonging to the power plant itself or to a public telephone network. The remote control system has not to handle a particularly large number of signals, in the case under consideration and no high demands are made, here, on the speed of signal transmission. Besides, the cable connection allows of taking advantage of direct-

current transmission and it is not necessary to reckon with service failures on the pilot line. The working conditions of the remote control system are, thus, relatively simple and can be fulfilled by means of inexpensive equipment. At the other extreme, is the case of the supervision of stations belonging to complete distribution networks. Here the remote control or remote signalling arrangement is an important part of the technical equipment for the load dispatcher of the whole service. In this case, one demands of the remote-control apparatus the transmission of hundreds of different signals, whereby the speed of transmission must be as high as possible. Above all, there are often big distances to bridge over, so that one has to have recourse, from an economic point of view, to signal transmission by high-frequency currents or other means which may be subject to transient disturbances. The remote control plant has thus to satisfy the highest demands imaginable as regards capacity and reliability of service.

Brown Boveri has, therefore, developed their designs in two directions. In order to meet all conceivable demands, a remote control equipment of the coded impulse system has been worked out. At the same time, for cases working under less difficult conditions, especially for the remote control of individual small plants, they have retained a very simple and easily supervised construction according to the well tried-out-method of direct pilot line switching, that is a system according to the single impulse process. For both methods of construction, fundamentally, the same type of switching apparatus and also, as far as possible, the same individual relay circuits have been used. They can only be distinguished from one another by the fact that the set of relays for the formation and dissolution of impulse codes is not found in the single impulse system and also that the method of moving the selector differs. A summary of working methods of both arrangements is given in the next paragraphs.

### III. THE DESIGN ACCORDING TO THE SINGLE IMPULSE SYSTEM.

A characteristic of the single impulse process is that every control and every return signal corresponds to a special switching position of the rotary selector. Since that process does not protect against normal service line failures, it should only be used for installations with pilot lines laid in cables. In this case an impulse transmission by means of direct current is allowable, whereby the number of signals, through using polarized receivers, can be doubled. The control and signal impulses are made use of at the same time for the synchronous step-by-step movement of both selectors. At the initiation of

a signal, not only will the impulse corresponding to this signal be sent out, but the positions of all control- and signal-contacts will be passed over and touched, whereby in every position of the selector an impulse is transmitted, which moves the selector by one step forward. The polarity of the impulse will be decided by the position of the corresponding control or signal switch. The moving-on of the selector is effected independently of the polarity while the corresponding receiving organ (control or position signalling relay) will be brought to the position corresponding to the polarity of the impulse. By changing over a control switch, or by an automatic changing of position of a supervised organ, the selector, which otherwise remains in the rest position, is caused to make a complete rotation. The synchronous running of the selectors is assured by there being alternate control and signal positions along their periphery. In the control positions, the feeding of the pilot-lead takes place from the control station and in the signal positions, on the other hand, it takes place from the remotely controlled station. Thus, the step-by-step movement depends on one selector being in the sending position and the other selector in the

corresponding receiving position. Should the two selectors fall out of step, due to some disturbance, the mutual switching-on movement is stopped, since both apparatus simultaneously come in a receiving position from which no further switching current impulse is transmitted. This causes a time-relay to begin to function in both stations, which cuts off all receiving apparatus from the source of current and switches over the selector drive to a local automatic breaker. The pilot lead can then be put under tension

by actuating a push-button switch, upon which both selectors move towards their respective rest positions independently of one another. It must also be mentioned that not all control and signal relays need be constructed as polarized apparatus. They are then not actuated by the remote transmission impulse itself, but by the insertion of a common polarized impulse receiver, the said relays being energized from a local source of current. This indirect connection system of the reception apparatus has also the advantage that, in spite of a stronger construction of the switching apparatus, a pilot line of smaller transmission capacity, for instance, a long telephone line of small section, can be made use of.

The described design of the single impulse control system is characterized by the small amount of apparatus required and the clearly laid-out connections. The rotary selectors used have, usually, 51 switching positions, so that they are sufficient for the control and signalling indication of 25 organs, each with two positions. For each remote operation the following apparatus is required:— a control switch, a control double relay, a double relay at the emitter end and a position-indicating relay for each signal. Fig. 4 shows a selector equipment which consists of not only the rotary selector, but also of the relay for the reception of polarized impulses and for the automatic supervision of disturbance. A signal-reporting relay is shown in Fig. 5 and a control double relay is shown in Fig. 6. The time of rotation of the selector, i. e. the longest possible time for the execution of a control and signal operation is about five seconds, with this design.

#### IV. THE DESIGN ACCORDING TO THE CODED IMPULSE SYSTEM.

The coded impulse system of remote control is used for a plant either with a very big number of signals or with a pilot line liable to trouble, where direct-current transmission is eliminated because a metallic connection between the pilot line and the apparatus connected up is inadmissible. Thus,

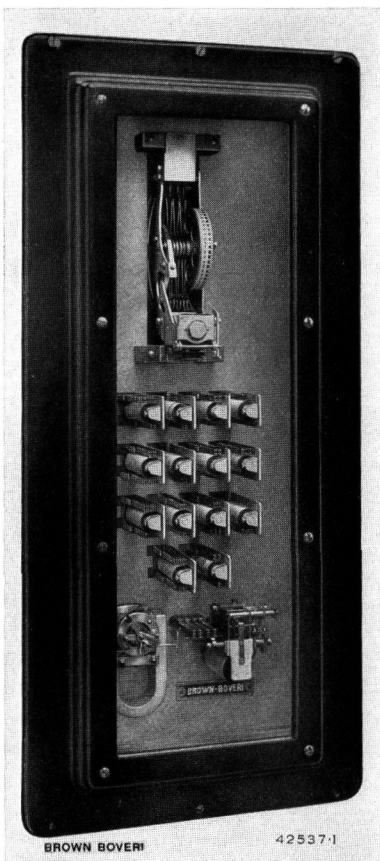


Fig. 4. — Remote control by selectors according to the single impulse process, year 1935.

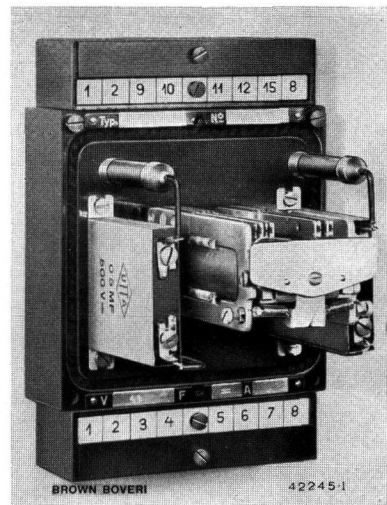


Fig. 5. — Position-indicating relay in individual housing, cover removed.

one is no longer free to choose the kind of current used for remote transmission. The Brown Boveri coded impulse control takes this fact into account, in so far as it works with direct current in exactly similar manner as with alternating current of any frequency, whereby for both senses of transmission (controlling and signalling back) a single kind of current only, for example, alternating current of a single frequency or modulated carrier wave suffices. The local circuits at the sending station and in the remotely controlled station are independent of the pilot circuit and are operated in all cases by direct current taken from a small battery or a metal rectifier. With the design according to the coded impulse process, as well, the selectors are normally at rest and are made to complete one rotation in order to transmit a control order or a signal. The selectors do not close the receiving circuit directly, but through intermediate relays, the so-called combination relays, the connections to the contacts of which form the individual receiving circuits. The advance movement of the selectors takes place, as in the single impulse system, by means of current impulses sent over the pilot line. The number of impulses is the same for every dispatch. These impulses cannot be made use of directly to actuate the signal receiving relays. In order to transmit a certain signal

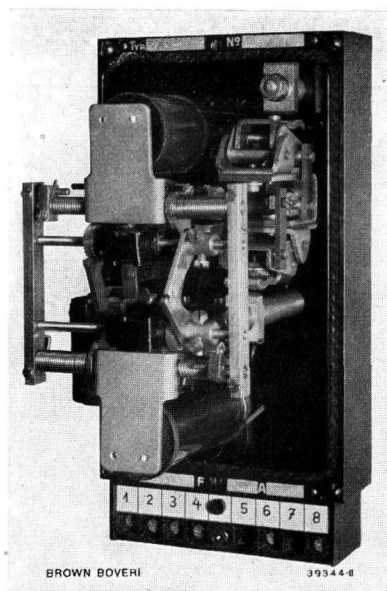


Fig. 6. — Double control-contactor with automatic anti-pumping device and closing contacts, for 250 A.

number, the selector is retained in a given position for a short time, which may be about 0.1 seconds. This takes place through the insertion of a pause in the impulse transmission. A time relay in the receiving post actuates the receiver-intermediate relay, which corresponds to the selector contact which the brush arm is in contact with. A holding circuit causes every receiver-intermediate relay, which is once excited, to remain attracted, till the end of a full rotation of the selector. The number of the lengthened impulse pauses is, also, the same for all signal transmissions. Thus the selector equipment can be built for one,

two and three position signals. The number of receiver-intermediate relays excited during a rotation is supervised by a special counting connection. Having moved through all the positions, which are connected up to receiver-intermediate relays, the selector comes to a special test position. In this position the transmission of further impulses from the signalling station is interrupted and a checking impulse is sent from the apparatus at the receiving end. This impulse will be sent out, only, if the right number of receiver-intermediate relays is excited and the station at the sending end can receive it only if the selector is found to be in the testing position. In this way it will be automatically determined whether all the impulses arrive at the receiving end, or whether one or more current impulses are suppressed or are induced by external voltages. When the test impulse arrives and the right choice of receiver-intermediate relays is confirmed, the transmission of further switching impulses, having a fresh short-time stop of the selector, in order to distinguish the order for switching-in and switching-out of the selected organ, is effected. This concludes the process of control transmission and the selector at the receiving end is brought to an operating position, in which the contacts of the excited receiver-intermediate relay are fed, so that the selected circuit is brought into action. The operating position is followed by three further positions, out of which two are meant for the return signalling of the accomplishment of the switching-in or out and one for a cutting-out impulse. This latter impulse will always be sent from the control post, and only if the selected position-announcing relay is in the position corresponding to that particular incoming return signal. If this is not the case, the "cut-out" sign is suppressed and a new rotation of the selector takes place with a further selection and actuation of the position-announcing relays. At each starting of the selector, the duration of the impulse for the first selector step will be lengthened with the help of a time relay, and the selectors can only leave their position of rest when a prolonged impulse of this kind comes in. If a selector is not in its rest position when this occurs, it will automatically be brought into this position and in doing so it applies a voltage to the pilot lead for as long a period as is necessary for it to reach the rest position. There is, thus, an automatic guarantee that the selector starting times will always be the same, a test connection for the continuation of the synchronous movement of both selectors till the end of the process of selection, and a further supervision of the correct transmission of impulses and pauses and the actuation of the receiver relay.

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The oscillogram of the current imposed on the pilot-lead, shown in Fig. 7, illustrates the procedure

more clearly than does the above description. The oscillogram shows also the high-speed of transmission of the device, which requires only a time of about two seconds for the execution of a control operation together with the position announcement, including the time proper for actuating the switches.

of signals and supervisory circuits. However, the control switch, the control double relay and the position signalling relays, are exactly the same. The equipment for coded impulse remote control is manufactured in three sizes, and for actuating and position signalling for 15 organs with signals of one figure, for 36 organs

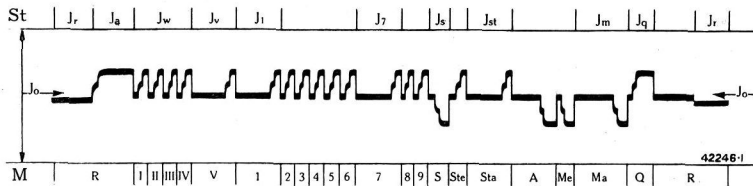


Fig. 7. — Oscillogram of the impulse groups to transmit a control and a position indicating signal.

- |   |  |
|---|--|
| Positions of selectors:—  | <i>J<sub>o</sub></i> . Line of no current.   |
| 1—9. Positions for choice of signals.                           | <i>J<sub>r</sub></i> . Rest-current for continuous supervision.                                    |
| A. Position for carrying out impulse.                           | St. Current in "control" sense.  |
| 1—V. Position for preliminary selection (selection of station). | <i>J<sub>v</sub></i> . Impulse to close combination relay V (choice of substation V).              |
| <i>M<sub>a</sub></i> . Position for signalling back "Out".      | <i>J<sub>w</sub></i> . Impulse to move selector round without effect.                              |
| <i>M<sub>e</sub></i> . Position for signalling back "In".       | <i>J<sub>1</sub></i> and <i>J<sub>7</sub></i> . Impulses to close combination relays of signal 17. |
| Q. Position for signalling acknowledge-                         | <i>J<sub>m</sub></i> . Impulse pause for back signal.  |
| R. Position of rest. [ment.                                     | <i>J<sub>q</sub></i> . Acknowledgement signal.   |
| S. Position for testing selector synchronism.                   | <i>J<sub>s</sub></i> . Impulse for selector synchronism control.                                   |
| <i>St<sub>a</sub></i> . Position for control impulse "Out".     | <i>J<sub>st</sub></i> . Impulses pause for control order emitted.                                  |
| <i>St<sub>e</sub></i> . Position for control impulse "In".      |  |
| Current characteristic:—  |  |
| <i>J<sub>a</sub></i> . Starting-up impulse.                     |  |
| M. Current in signalling back sense.                            |  |

As compared to the single impulse process in which the duration of individual impulses and pauses plays no essential part, the impulse process makes use of time-relays which maintain their time lag exactly and independently of accidental variations of the auxiliary source of current. Fig. 8 shows a relay which can be set for a contact time lag of 60—120 milli-seconds, and which can also work very exactly when voltage variations up to 30% take place. The robust construction of this relay is especially remarkable; it guarantees a long life even though the frequency of switching be very great.

with signals of two figures and for 180 organs with signals of three figures. For big plants, it is advantageous to bring the position-signalling relays within common housings in order to reduce the space required. In such cases, 36 double relays are grouped in a single housing, as Fig. 9 shows.

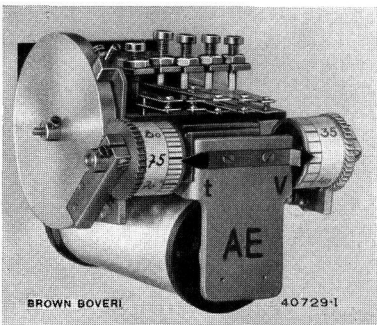


Fig. 8. — Relay with time lag independent of voltage and which can be set from 60 to 120 milliseconds.

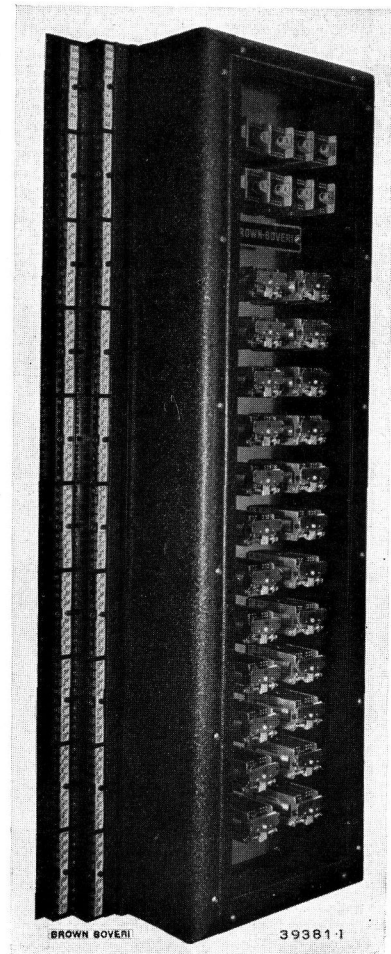


Fig. 9. — Double relays in common housing for position signalling of 36 remote-controlled breakers.

### V. THE CHARACTERISTICS OF THE BROWN BOVERI APPARATUS.

As already mentioned, the principle of selector remote-controlling gears and also such as work on the coded impulse process, have become common property to-day. Both designs described here show, however, a series of special advantages, the most important among these being the automatic supervision of all signalling circuits. For switching supervision with local control, it has been taken for granted for a long time that all supervisory circuits are to be so connected

that the occurrences of trouble in the equipment should not produce the effect of a wrong state of affairs, but should show up the troubles as such. This very important stipulation is fulfilled in the design under consideration, as well. There are double relays normally energized connected to the signalling contacts to be supervised. If a circuit fails, the relay which falls, initiates a signal transmission and an indication is given in the control post, which signal circuit is affected by the failure. In similar manner, the receiver relays at the control post are supervised, and it can never happen that a signal is suppressed as a result of non-operation of the remote-control equipment or of one of the connecting leads. The rest-current supervision extends also to the pilot leads, whereby distinction is made between transient and intermittent troubles. This automatic supervision is made use of, fundamentally, in the same way in the system which works on the single impulse process as in the coded impulse remote-control system. In the latter system the indication of trouble, in the pilot-lead and the individual signal circuits, is effected by means of special trouble indicating lights. In the single impulse system this is left out and the reporting of trouble is carried out by stopping the selector in the corresponding control or signal position and by three common signal lights showing the place of failure (control post, pilot lead, or remote-controlled plant). The number of the affected circuit can be read-off from the selector.

Further, in the construction of the equipment, special care was taken in order that the remote-control devices be sufficient to meet the demands of communication engineering as well as those of heavy current engineering. The individual apparatus are, therefore, so built that the room taken up by them is not more than what one is used to, with communication equipment. Nevertheless, all the usual measures taken in heavy current plants, as for example, measures as regards variations of the auxiliary voltage, terminal marking for every individual connection, well-secured screw terminals, dust-proof housing, etc. are found here. The equipments belonging to the remote-controlled heavy-current plant, for instance the control relay, satisfy throughout the safety regulations relating thereto, and have a test voltage of  $2 E + 1000$  V. All the apparatus connected to the weak-current leads correspond similarly to the stipulations of communication engineering, so that the smallest energy of transmission, less than one voltampere, will suffice. The isolating of the pilot leads in the coded impulse process is carried out through isolating transformers, the test voltages of which depends upon the rated voltage of the high voltage line which goes over the high-tension poles.

## VI. REMOTE METERING.

The equipment for remote metering forms the second big group of apparatus for remote supervision. Its principle is the transformation of the measured quantity into an auxiliary quantity, which cannot be altered by the changing properties of the pilot leads. One expects the remote metering to be able to transmit the instrument readings over any lines with changing resistance and insulating properties. The process which is generally carried out to-day, consists of transforming the measured values into a frequency proportional to the said values, which, nevertheless, will not be transmitted as sinusoidal alternating current but as periodic impulses emitted as D. C. or A. C. A revolving apparatus, which is built as a sort of electricity meter, works as the emitting apparatus and during every rotation it closes a contact. By these contacts the pilot lead for measurements is periodically placed under tension, whereby the frequency of impulse, i. e. the number of impulses in the unit of time, gives the measured value. Fig. 10 shows an impulse frequency emitter of this type used in power-measurement work for alternating current with unequally loaded phases. At the receiving post, the frequency on the transmitted impulse must be represented by the position of the pointer. Most devices to be found on the market, built to this principle, use receivers which transform the impulse frequency back into an electrical magnitude, so that it can be led to a normal measuring instrument. This new transformation is, however, neither necessary nor suitable, in so far as it is not a case of the sum of several remote

meterings. The indicating instrument should preferably not be an intensity-measuring instrument in which its errors in measurement are added to the unavoidable inaccuracies of the emitter. Brown Boveri have developed a process by which the transformation of the impulse frequency into an indicating position is managed by pure mechanical means. The process

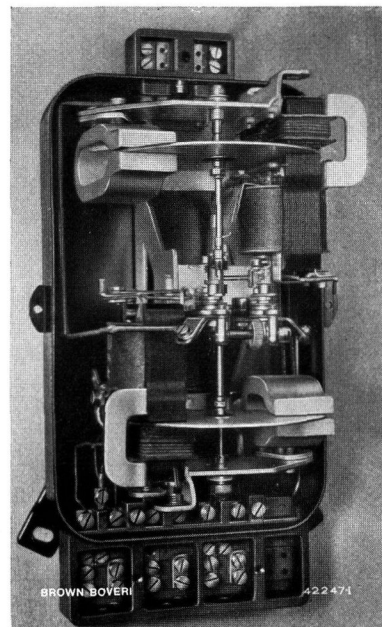


Fig. 10. — Wattmetric remote-metering emitter on the impulse frequency principle.

consists of a comparison, at the receiving post, of the measuring frequency with a second impulse frequency of constant value produced in the receiver station by a contact pendulum. The pendulum can be common to a number of remote measurements, and its accuracy is several times that of an electrical measuring instrument.

The fundamental construction of the remote metering receiver is given in Fig. 11. The incoming impulses are led to the coil of the magnet  $M_1$ . Its armature, with the help of ratchets  $a_1$ ,  $a_2$ , and  $a_3$  actuates the toothed wheels which will at least be three in number. The pointer  $F$  of the instrument rotates against the tension of a spring, with the rod which carries it. This rod  $S$  is always carried away by the wheel which makes the biggest angle of deflection. The coil of the second magnet  $M_2$  is connected to

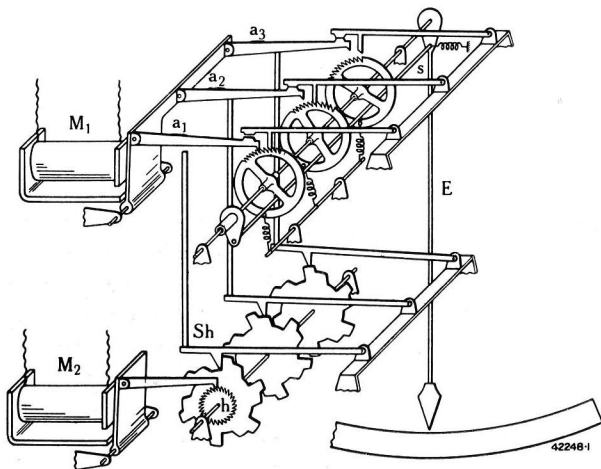


Fig. 11. — Fundamental design of a mechanical receiver for remote-metering according to the impulse frequency principle.

the electrical contact pendulum and it maintains an impulse after equal intervals of time, for instance after every second. With this, the toothed wheel  $h$  is moved further, step by step and its motion is transmitted through the cam wheels which are coupled to it. The motion of the thrust lever  $Sh$  is taken from the cam wheels. In the lowest position, there is no connection between the thrust lever and the switch ratchets, so that the latter are brought into mesh with the wheels. The armature of the magnet  $M_1$  can, therefore, move a toothed wheel further, step by step. In the medium position of the thrust lever, it lifts the switch ratchets so high, that they come out of mesh and no further movement happens to the wheel. In the highest position of the thrust lever the switch ratchets will be raised so that the stop-pawl is disengaged, as a result of which the wheel turns back into its original position.

For the actual operation of the apparatus, eight wheels are necessary, and not three as shown in Fig. 11. The interval of time for the adjustment of the pointer with falling measured values, is shortened to a third by this. Fig. 12 shows such an indicating apparatus with an arc-shaped scale to fit in a round housing.

As compared to the electrical measurements, the mechanical indicating apparatus has a big torque at its disposal. The establishment of reliable limiting contacts presents no difficulties. For the addition of several measured values, the receiver will be coupled to rotating resistances which feed an electrical adding instrument by a parallel connection.

In many cases, for conveying several remote measurements, a single pilot circuit only will be available. If, in spite of this, all the measurement magnitudes have to be shown simultaneously in the receiving station, the same process, on which the remote control apparatus is built, can be used, namely the periodic connecting together of the emitter and receiver, which correspond to each other. As the remote metering

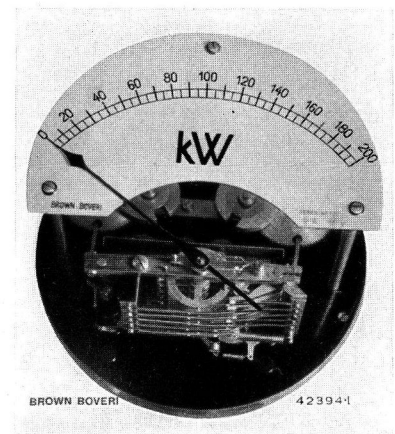


Fig. 12. — Remote-metering receiver with circle scale for lodging in a circular housing.

receiver retains the last measuring value given, when the remote metering emitter and the local comparison impulse emitter are simultaneously and temporarily cut out, a selector pair is used for periodic switching over, which is controlled from the contact pendulum of the emitting station; when this is done, the further switching on movement is carried out, fundamentally, as in an impulse remote-control equipment.

Remote measuring devices also call for automatic supervision of the circuits and especially of the pilot line. Rupture of a circuit would otherwise lead to the erroneous indication "zero" of the magnitude measured. The process described, when on the subject of remote-control equipments, of rest-position supervision of the pilot lines can also be applied to remote metering, so that the latter can enjoy the same quality of great service reliability, which characterizes the Brown Boveri remote control equipments.

(MS 976)

O. Plechl. (Mo.)

## THE BALANCING OF MASSES IN ROTATING BODIES.

Decimal index 621-755.

### I. INTRODUCTION.

THE speeds called for by modern machine designs are constantly increasing and require perfect balancing of the rotating masses involved. This is attained by the addition of weights, which are added during the balancing tests. Efficient balancing machines are, now, available to simplify the work which was entirely entrusted to specialists, in earlier days. As, however, balancing is, often, an urgent necessity in plants — power stations or industrial plants — where the aforesaid special balancing machines are not available, it may be of interest to give a summary, here, of simple balancing methods which can be applied. This will be done without going into those theoretical principles which govern the balancing of masses and have been examined exhaustively in technical treatises, such as Stodola's work on the steam turbine, for example.

To begin with, it will be assumed that the rotor to be balanced is so supported in its bearings that it is only free to vibrate in a horizontal plane and that, when at rest, its spindle always returns to the same position.

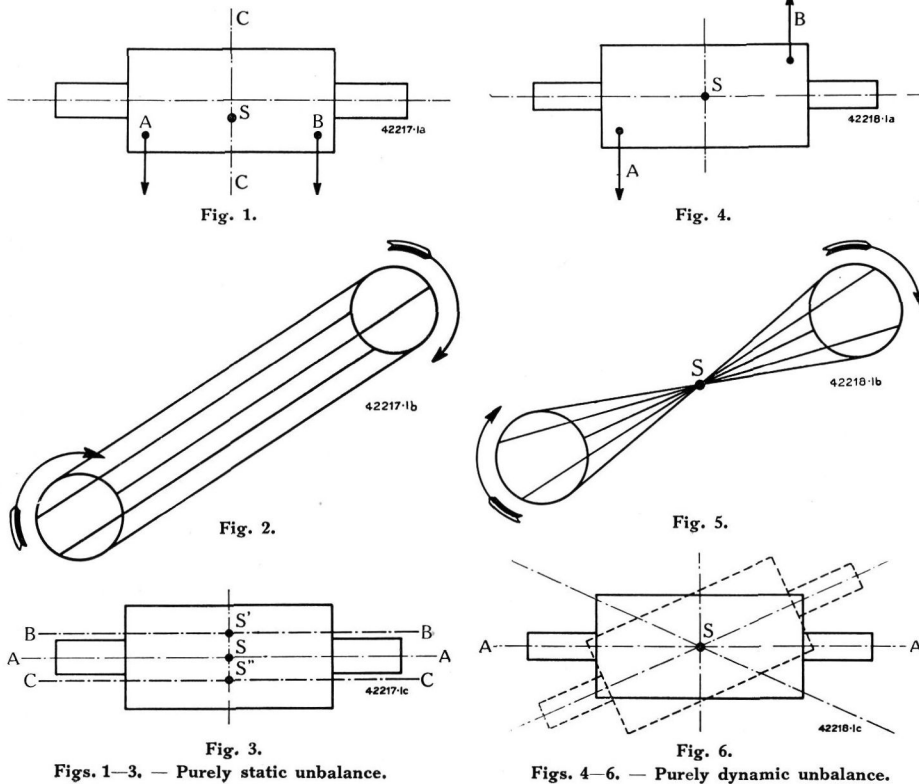
To begin with, there are three characteristic cases of unbalance, each of which is marked by its own kind of vibration.

1. *Purely static unbalance.* — The distribution of weight in the rotor is symmetrical as regards the medium plane C-C, but the center of gravity is not located exactly on the axis of rotation (Fig. 1). Two forces A and B of equal magnitude then act on the rotor, symmetrically to the point of gravity. If, now, the rotor were free, i. e. could move without being constrained by the bearings, its axis would describe the track illustrated in Fig. 2. As, however, the rotor is only free to move in the horizontal plane, a vibration is set up, according to Fig. 3, in which the rotor axis A-A is displaced constantly parallel to itself.

2. *Purely dynamic unbalance.* — The distribution of weight in the rotor, as shown in Fig. 4, is symmetrical as regards the center of gravity which is located, in the present case, on the rotor axis. If the rotor could rotate freely, the axis would describe a movement, under the influence of forces A and B, as illustrated in Fig. 5. As, however, it can only move freely in a horizontal plane, a rotary oscillation is set up round the center of gravity, as shown in Fig. 6.

3. *Mixed unbalance.* — Case 1 and 2 alone are of very rare occurrence and, practically, all cases observed, are a combination of 1 and 2. This combined unbalance can, however, be decomposed into a purely static one and a purely dynamic one, generally located in different planes.

Before going further into the question of the said decomposition of unbalances, a few words should be said on the relation between unbalance weight and oscillation amplitude. Fig. 7 shows the position of a rotor rotating in bearings which only allow lateral displacement, Fig. 7 illustrating the moment of maximum displacement to the right. Let  $x$  be the displacement from the medium position and  $K$  the point of maximum displacement (which can be determined in the manner explained later on). Point  $K$  lags by an angle  $\varphi$  (referred to sense of rotation) behind the unbalanced weight  $A$ . For a given



Figs. 1-3. — Purely static unbalance.

Figs. 4-6. — Purely dynamic unbalance.

balancing equipment and a given rotor this angle  $\varphi$  (sometimes incorrectly termed phase displacement) is, solely, dependent on the speed of rotation, while the amplitude of oscillation is dependent on the said speed and on the magnitude of the unbalance.

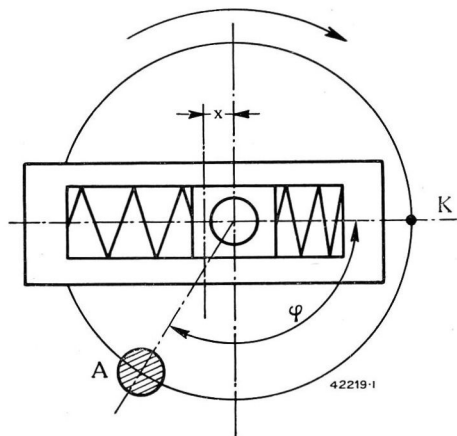
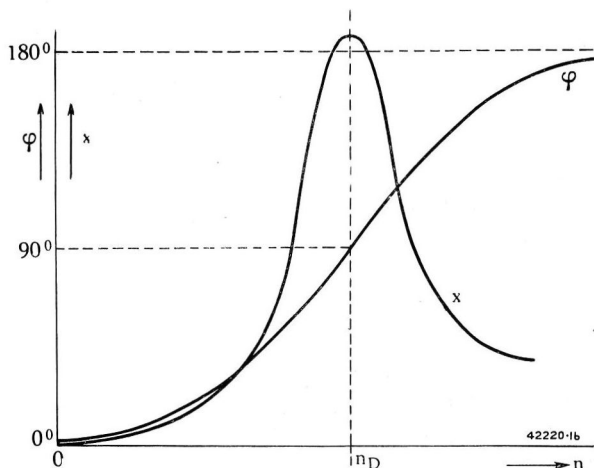
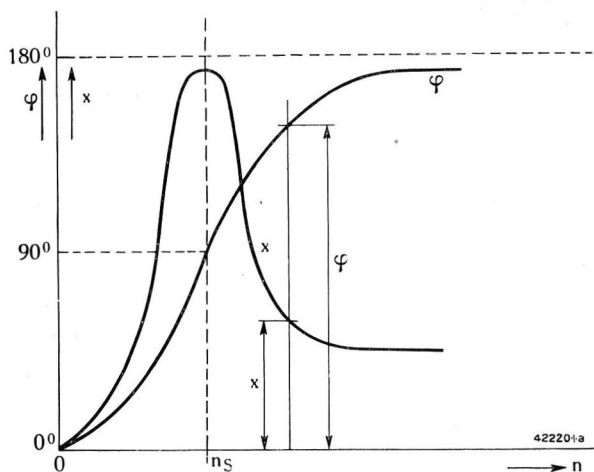


Fig. 7. — Amplitude of vibration and point of maximum displacement.



Figs. 8-9. — Angle  $\varphi$  and amplitude of vibration.

n. Speed of rotor.  
 $n_s$ . Static resonance speed.  
 $n_D$ . Dynamic resonance speed.  
 x. Amplitude of vibration.  
 $\varphi$ . Angle between point of maximum displacement and the unbalance.

The curves of Fig. 8 give the value of the angle  $\varphi$  and the amplitude of oscillation  $x$  in function of the speed. These curves show that there is a speed at which — and in the neighbourhood of which — the amplitude of oscillation is very great. This is due to the fact that the speed of the rotor comes into resonance with the oscillations proper of the whole system composed of the rotor and its flexible bearing supports. At these so-termed resonance speeds the angle of lag  $\varphi = 90^\circ$  and, at much higher speeds, this angle reaches nearly  $180^\circ$ . The curves of Fig. 8 are independent of the sense of rotation.

In cases of purely dynamic unbalance, conditions are similar. Here, also, angle  $\varphi$  and amplitude of vibration  $x$  are given under the form of curves (Fig. 9). The only difference is that the sense of maximum displacement  $x$ , on either side of the center of gravity, are opposed to each other and grow in direct ratio to the distance  $l$  from the said center of gravity (Fig. 10). The resonance has the same character as in purely static unbalance and appears again at  $\varphi = 90^\circ$ .

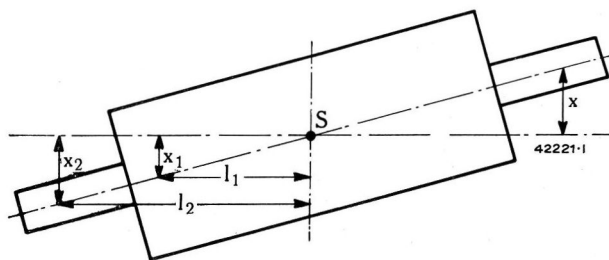


Fig. 10. — Amplitude of vibration in the case of purely dynamic unbalance.

As Figs. 8 and 9 show, the static and dynamic resonance speeds do not generally coincide. Their relative position depends on the shape of the rotating body, as is easily proved by the equations which govern  $\pm$  oscillations. For the usual shapes of turbine and generator rotors, the dynamic resonance speed is about twice as high as the static one.

II. PRACTICAL BALANCING.

The rotor to be tested is cradled in the manner illustrated in Fig. 11. It has, thus, the necessary freedom to move in a horizontal plane. As, now, a

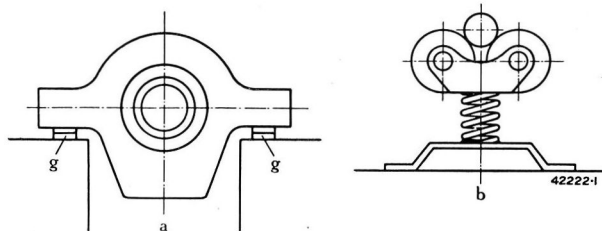


Fig. 11. — Support of the rotor allowing of vibrations in the horizontal plane.

g. Rubber pad support.

rigid rotor, which is well balanced at a given speed, remains steady at all speeds, the balancing equipment can be so designed that a low resonance speed is created. For big rotors, resonance speeds of between 200, 250 r. p. m. are chosen and, for small rotors, up to 600 r. p. m. The resonance speed is determined by the thickness of the rubber pad in devices such as that shown in Fig. 11a and by the dimensions of the spiral spring in devices such as that of Fig. 11b.

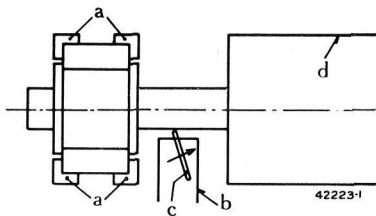


Fig. 12. — Equipment for making the pencil marks.

- a. Rubber pad supports.
- b. Rigid independent support put up.
- c. Coloured pencil.
- d. Rotor.

The drive is best carried out through a belt from a separate motor.

In order to determine which point has the greatest displacement, a firmly supported coloured pencil is brought up close

to the shaft journal of the revolving rotor (Fig. 12), until it touches the journal lightly; the shorter the coloured streak produced, the worse the balance and the easier the task of balancing. In judging the indications thus produced, a beginning must be made from the middle of the streak (Fig. 13).

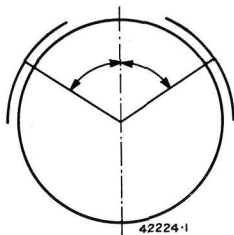


Fig. 13. — Determination of results of markings.

In order that a free vibration be produced, the driving belt is slackened before the marks are made. When passing through the speed desired (when the speed is dropping), marks are made at both shaft ends, when possible. When several marks are made, the same speed must be adhered to, exactly. A primary

condition for good balancing results is, obviously, that the journals should be straight and run true.

In order to shorten the coming paragraphs, it should be said here that by the addition of static-correction weights is meant putting weights on the rotor according to Fig. 14a and by the addition of dynamic-correction weights is meant putting weights on the rotor according to Fig. 14b. At the beginning of the operation, the rotor is allowed to rotate first in order to ascertain at what speeds the static and dynamic resonances appear.

### III. STATIC AND DYNAMIC BALANCING WITH BOTH SENSES OF ROTATION.

Marks are made on the rotor for both senses of rotation of the latter, in one sense with a red

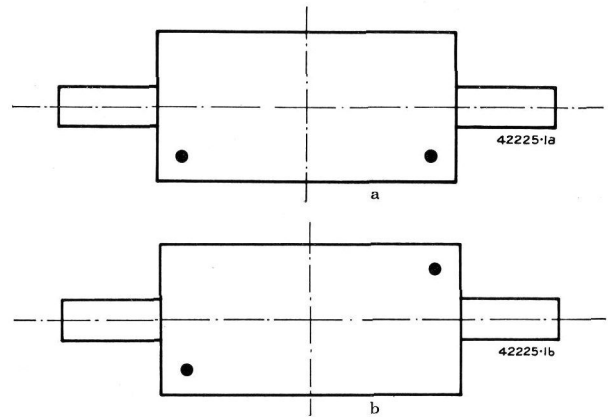


Fig. 14. — Addition of correction balance weights to the rotor.  
a. Static. b. Dynamic.

pencil, for example, and in the other with a blue one. For this the r.p.m. must be about 10% above the static resonance speed. Further, care must be taken that the marking speeds, in forward and reverse rotation, are as equal as possible. The symmetry line L-L between the marks determine the plane of unbalance (Fig. 15). *To speak generally, the marks always lag behind the point of unbalance or "heavy spot". The correction weight to be added must be placed behind the mark.*

The magnitude of the correction weight must be ascertained by tests made with repeated runnings of the rotor. If the pencil marks are always recorded on the same side of the shaft, and if the vibrations at the resonance speed seem less accentuated than before, the correction weights put on are still too small. If, however, the marks appear on the other side of the shaft, the correction weights added are too big. In this way tests are continued until running at the speed corresponding to static resonance is, practically, smooth.

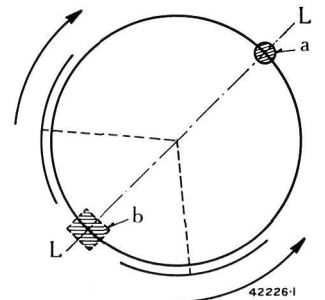


Fig. 15. — Determination of the plane of unbalance.

- a. Unbalance (unknown).
- b. Correction balance weight to be added.

It is now possible to begin investigation of the dynamic unbalance; for this it is advantageous to choose a speed which is also about 10% above the resonance r.p.m. There, again, pencil marks are made for both senses of rotation. The marks should now appear on the two opposite sides of the shaft journals.

If the said marks are not opposite each other, this is a proof that there is still some static unbalance. The correction weights for dynamic unbalance

are added according to the same principle as used for static balancing.

By repetition of this process and by appropriate modification of the correction weights, smooth running at the dynamic resonance speed is, finally, attained. Finally, the static markings are repeated, again, so as to make whatever adjustments may still be necessary. If this has to be done, the dynamic balancing must again be tested.

IV. STATIC AND DYNAMIC BALANCING WITH ONE SENSE OF ROTATION.

As opposed to the two methods just described, the speed with which tests are begun, in the present case, is at least 30% above the dynamic resonance r.p.m. Then, according to how the pencil markings show, either static or dynamic balancing is begun with. The markings, only one on each shaft journal, have to be made with great care, so that they are of short length. It is recommendable to repeat the first marks two or three times before determining

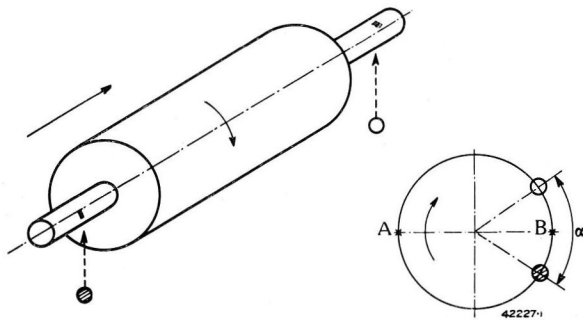


Fig. 16. — Static and dynamic balancing with one sense of rotation  $\alpha < 90^\circ$ .

their exact location. In Fig. 16 the mark O designates the middle of the marks on one journal and ● that on the other journal.

According to the position of the first marks, several different cases can be differentiated.

1. The marks are so made that angle  $\alpha$  (Fig. 16) is smaller than  $90^\circ$ . In this case, angle  $\alpha$  is divided into two equal parts and the line of separation gives, approximately, the position of the plane of static unbalance. The balance fault is located at A and the counter weight should be added at B. This static balancing is carried further until the vibrations have practically disappeared when the rotor passes through the static resonance r.p.m. The modified weight should always be placed on the same spot B. The better the static balance the further the marks travel from one another until they are, finally, opposite one another. Dynamic balancing is, now, carried out in the plane determined by the two last marks located opposite each other. This is done by locating the correction weights on the said marks, or, still better, about

$10^\circ$  behind them. Balancing is now continued weights being always placed on the same spot until running has become considerably smoother when passing through the dynamic resonance r.p.m. In this dynamic balancing method the marks tend to move towards each other again and end by coming on the same side. The plane thus determined which is again statically unbalanced does not, generally, coincide with the one in which static balancing was carried out earlier (B in Fig. 16). Static balancing must, again, be carried out in this new plane until the marks are again opposite each other. Then an improvement of the remanent dynamic unbalance is effected and the process goes on in an alternation of static and dynamic balancing operations until the rotor runs satisfactorily, at all speeds.

2. If the middle of the marks are so located that  $\alpha$  is bigger than  $90^\circ$  (Fig. 17), dynamic balancing is begun with and this in plane L which makes the same angle with the radii through the middle of the marks (Fig. 17). Correction weights are placed at A and B. Balancing is continued in this plane until smooth running is attained when the rotor passes through the dynamic resonance speed. As this dynamic balancing progresses, the two marks have moved towards each other, and finally appear on the same side and give, approximately, the plane of the static unbalance still to be dealt with. Balancing is pursued, as explained under 1, until the rotor runs smoothly at all speeds.

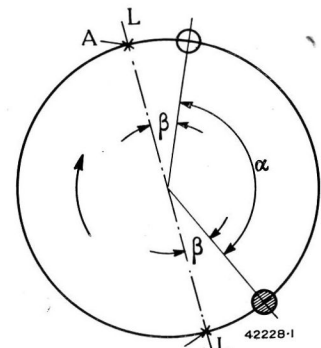


Fig. 17. — Balancing with one sense of rotation  $\alpha > 90^\circ$ .

3. A special case is presented when one marking runs all round the journal, while the other one is very short and distinct. The rotor vibrates strongly at one journal and practically, not at all at the other. In this case, static and dynamic unbalance are nearly in the same plane. A start is made with static balancing in the plane of the short marks, and this is carried on until running becomes smooth when passing through the static resonance speed. In the meantime the marks round the journal disappear and are replaced by a mark which gets more and more definite. If smooth running at static resonance speed is attained, the marks indicate the plane of dynamic unbalance which plane does not deviate much from the one of static unbalance. Dynamic balancing is now pursued in the newly determined plane, as explained under 1 and 2.

V. RELATION OF THE STATIC TO THE DYNAMIC RESONANCE SPEED.

The equation of the vibrations proper of the system in the case of the static resonance speed (the rotor shaft oscillating parallel to itself, according to Fig. 3) are as follows:

$$M \frac{d^2x}{dt^2} = -2kx$$

where

M = mass of rotor

x = amplitude of vibration and kx the spring force acting on each of the two bearings.

The number of the vibrations is given by this differential equation, being

$$n_{stat} = \frac{1}{2\pi} \sqrt{\frac{2k}{M}}$$

It is, thus, dependent on the spring strength of the support and the mass of the rotor.

In the case of the dynamic resonance speed, for the same rotor

$$\Theta \frac{d^2\varphi}{dt^2} = -2k\ell^2\varphi$$

$\Theta$  is the moment of inertia of the mass referred to medium point S of the vibration; k is the spring

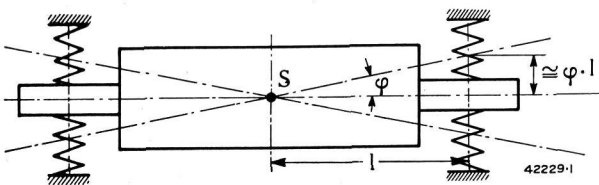


Fig. 18. — Conditions in the case of dynamic resonance speed.

constant, as before, of the support, while angle of rotation  $\varphi$  and dimension  $\ell$  can be seen in Fig. 18.

The number of vibrations is given, here, by

$$n_{dyn} = \frac{1}{2\pi} \sqrt{\frac{2k\ell^2}{\Theta}}$$

This means that the dynamic resonance speed of the rotor is dependent, apart from k, on the distance between bearings and the moment of inertia of the mass, i.e. for a given mass it depends on the shape.

The relation of the static to the dynamic resonance speed is thus determined by

$$\frac{n_{stat}}{n_{dyn}} = \frac{1}{\ell} \sqrt{\frac{\Theta}{M}}$$

VI. ULTERIOR BALANCING AT FULL SPEED.

This method is applied to advantage on machines on which it is easy to secure correction balancing

weights. The B case is difficult to handle and a removal of the rotor and its placing on an emergency balancing machine is the most expedient solution.

A. *Static unbalance* (discs, etc., rotors, in which only one journal vibrates strongly). The method assumes that the amplitudes of vibration, caused by an unbalance on a bearing, for example, are proportional to the unbalanced force in the rotor. This assumption is, certainly, correct for all amplitudes which can be allowed without danger for a machine running at high or full speed.

1. The amplitude of vibration is first measured before any alteration is attempted, this being done with a vibrometer or vibrograph secured to a bearing pedestal.

Alternatively, a dial micrometer can be mounted on a support independent of the set being balanced, and, resting against the bearing or shaft, gives a measure of the vibration amplitude.

2. A weight of known magnitude<sup>1</sup> is secured to any point a' (Fig. 19) and the machine brought to the speed chosen for balancing, which, if possible, should be its full-rated speed, the vibrations which then occur are measured. For example, the amplitude of vibration corresponds to 1.5 divisions of the instrument used.

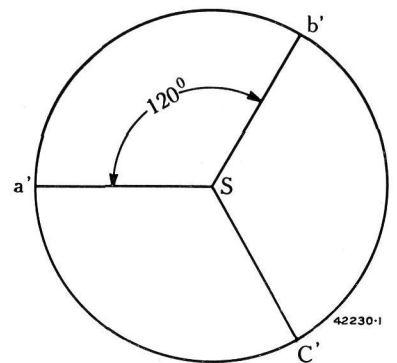


Fig. 19. — Addition of a weight of determined magnitude at a'; then at b' and, finally at c'.

3. The same weight is displaced on the same circumference by 120° (Fig. 19) and secured in position b'; the vibrations which arise are measured at exactly the same speed and sense of rotation and with *unchanged instruments*. The amplitude is, now, 3.5 divisions, for example.

4. The weight is, finally, secured at c', the amplitude being, for instance, 2.5 divisions, here.

From these four tests, which must be carried out at the same speed, the necessary data can be deducted to allow of ascertaining the magnitude and sense of the unbalance.

<sup>1</sup> The magnitude of the weight chosen must, of course, be in a certain ratio to the weight of the piece being balanced, if an effective influence on the vibrations is to be attained.

The surplus weight  $U$  present in the system forms resultants  $R_a$ ,  $R_b$ , and  $R_c$  with the weight mounted at  $a'$ ,  $b'$ , and  $c'$ , which resultants are proportional to the amplitudes measured, according to what was assumed. The parallelogram of forces (Fig. 20) shows, at once, that the end point  $O$  of the unbalance  $U$  looked for is located at the center of a circle having a radius of  $G$  dimension, and also that the end points  $a$ ,  $b$ , and  $c$  of the resultants  $R_a$ ,  $R_b$ , and  $R_c$  are also located on this circumference. Fig. 20,

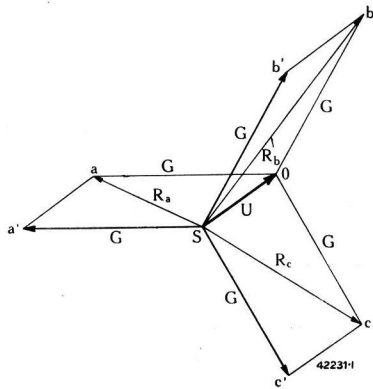


Fig. 20. — Parallelogram of forces.

thus, allows of reaching the following conclusion:— If it is possible to determine a point  $S$  on a circumference with center at  $O$  and a radius of the magnitude of  $G$ , the connecting straight lines of which to points  $a$ ,  $b$ , and  $c$  at  $120^\circ$  from one another are in the same ratio as  $R_a : R_b : R_c = 1.5 : 3.5 : 2.5$ , then  $SO$  is the unbalance sought for, both in magnitude and direction.

5. *Constructive determination of the unbalance* (Fig. 21).—The task is, therefore, to determine point  $S$  (Fig. 20), so that the connecting straight lines from  $S$  to  $a$ ,  $b$ , and  $c$  are in the same ratio to each other as  $R_a : R_b : R_c$ , which for the example under consideration is  $1.5 : 3.5 : 2.5$ . To this end, the weight  $G$  placed successively at  $a'$ ,  $b'$ , and  $c'$  (Fig. 19) is drawn in to a given scale both in magnitude and sense from a point  $O$  (Fig. 21).

First a straight line is laid through points  $a$  and  $b$  and perpendiculars drawn in at  $a$  and  $b$ . At  $a$ , the amplitude measured when the known weight was at  $a'$ , is marked off on the said perpendiculars (on both sides) to a given scale (1 division of the instrument = 1 cm for example). This amplitude was 1.5 divisions in the assumption made, or 1.5 cm to the scale. In  $b$ , the amplitude measured for weight in position  $b'$  is marked of on the perpendiculars to  $a-b$  (but only on one side). This is 3.5 divisions or 3.5 cm. By connecting up points  $x$ ,  $y$ , and  $z$  thus obtained, points  $A$  and  $B$  are determined on  $a-b$ . A circle is now drawn through  $A$  and  $B$ , having as center  $O_1$ . As is known, this circle is the locus of all points the connecting lines of which are in the same ratio to  $a$  and  $b$  as  $1.5 : 3.5$ .

The circle is, therefore, also the locus of the points of intersection of the resultants  $R_a$  and  $R_b$ ,

which are in the ratio  $1.5 : 3.5$  according to the measurements carried out.

In similar manner the locus of all points is, now, determined over  $b-c$ , the connecting lines of which are in the same ratios to  $b$  and  $c$  as  $R_b : R_c = 3.5 : 2.5$  (perpendiculars at point  $b$  and  $c$  to the line  $b-c$ , 3.5 cm being measured off in  $b$  and 2.5 cm in  $c$ , respectively, which leads to the determination of points of intersection  $C$  and  $D$  and to a circle round  $O_2$ ).

The third circle round  $O_3$  over  $c-a$  is only a verification of the correction of the diagram, and is also established in similar manner. The three circles intersect at points  $S$  and  $S_1$ . As, now, the lines of connection from point  $S$  to points  $a$ ,  $b$ , and  $c$  and those from  $S_1$  to  $a$ ,  $b$ , and  $c$  are in the ratios  $1.5 : 3.5 : 2.5 = R_a : R_b : R_c$ , two solutions for the magnitude and sense of the unbalance are attained in  $SO$  and  $S_1O$ .

By taking account of the scale of force chosen, the weight of  $U$  can be read off straight, and, thus, the magnitude and sense of the correction balance weight is determined.

It is possible to determine which solution is the correct one by comparing the amplitude of vibration

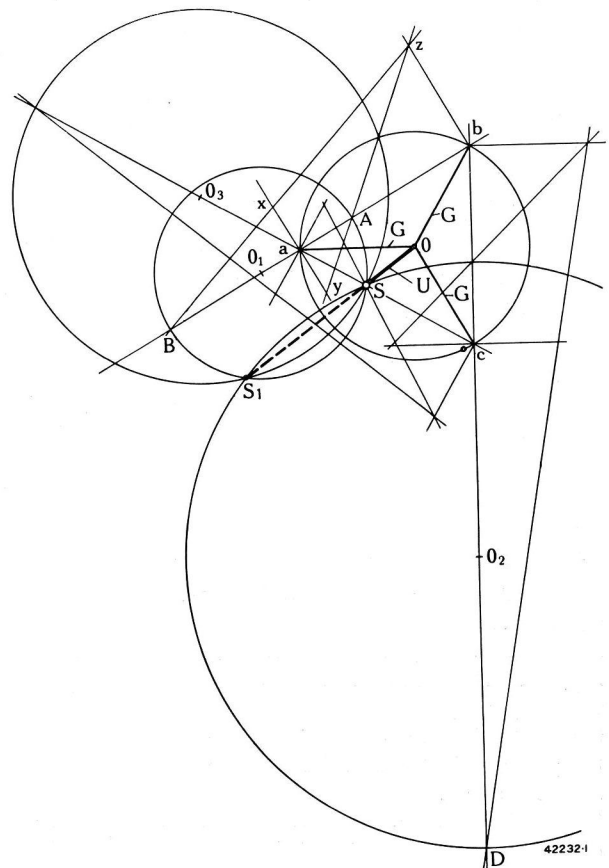


Fig. 21. — Geometrical determination of sense and magnitude of the unbalance.

determined before balancing began (see under  $A_1$ ) with one of the three amplitudes of  $R_a$ ,  $R_b$ , or  $R_c$ . As the amplitudes are proportional to the forces, a decision can be reached as to which solution is the correct one.

*B. Static and dynamic unbalance* (rotors of turbo-generators and of steam turbines).

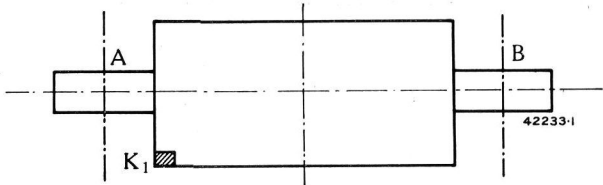


Fig. 22.

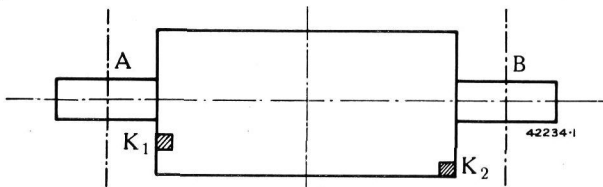


Fig. 23.

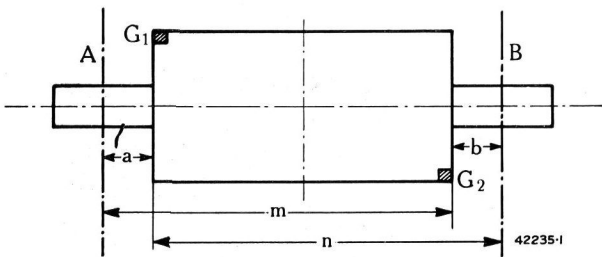


Fig. 24.

Figs. 22-24. — Placing and distribution on the ends of the rotor of the weights which have been determined according in Fig. 21.

1. Determination of the weight  $K_1$ , on one end of the rotor (Fig. 22) which compensates all forces and torques which act on the middle of the bearing as a result of a state of unbalance. This is effected by the method under A, by putting on a predetermined weight, three times (each point at  $120^\circ$  from the former one). The weight  $K_1$ , which is finally determined by geometrical construction according to Fig. 21, is then secured definitely in position.

2.  $K_2$  at the other rotor end is determined once  $K_1$  (Fig. 23) is in position. Thus, the whole effect of the unbalance on the middle of the bearing B is compensated. For the moment, however,  $K_2$  is not put on. If  $K_2$  were put on, after being determined according to Fig. 21, the rotor would run smoothly at B, but vibrations would be set up again at A, owing to the reaction of  $K_2$  on A. The necessity, therefore, arises to decompose weight  $K_2$  into weights  $G_1$  and  $G_2$  (Fig. 24) in such a manner that:—

- (a) The influence of  $G_1$  and  $G_2$  on bearing point B is the same as  $K_2$  alone.
- (b) The weights  $G_1$  and  $G_2$  do not create new forces, i. e. the sum of the torques generated by  $G_1$  and  $G_2$  as referred to B is equal to zero.

Put under the form of an equation condition a is

$$K_2 \cdot m = G_2 \cdot m - G_1 \cdot a$$

and condition b is

$$G_1 \cdot n - G_2 \cdot b = 0$$

$G_1$  and  $G_2$  can be determined from these two equations and can be secured on the rotor, being lodged in the plane passing through the axis and through  $K_2$ .

(MS 967)

F. Ribary. (Mo.)

NOTES.

**Quick-acting regulation of paper-making machine drives.**

Decimal index 621.34:676.2.05.

ONE of the essential conditions of every paper-making machine drive is the absolute maintenance of the working speed set to. Every arbitrary modification of the said speed means a variation in the thickness and, therefore, of the weight per square metre of the paper manufactured. If the fluctuations in weight exceed a certain value, set by the paper trade, the manufactured product may be refused by the buyer. In any case, the excess weight is not paid for so that more material is being delivered without a corresponding increase in price.

In order to maintain the working speed of the paper-making machine constant, in spite of load fluctuations and

of variations in voltage or frequency on the supply system, Brown Boveri make use of a quick-acting regulation the principal elements of which are a very sensitive quick-acting regulator, a tachometer dynamo and the requisite switching gear. The regulator proper is built to the design of the well-known Brown Boveri quick-acting regulator, thousands of which are working to-day; this apparatus is characterized by high precision combined with an efficient damping and recall, so that occasional speed fluctuations are suppressed at the moment of their initiation and this without any hunting. As opposed to the vibratory regulators working on the oscillation principle, the Brown Boveri regulator is subject to no wear and calls for no special supervision so that a very high degree of reliability in service is assured.

The regulator is influenced by the tachometer dynamo, which is either direct-coupled to the driving motor of the paper-making machine or is driven by belt or chain. Every

fluctuation in speed is expressed by a variation in the voltage of the dynamo, which, in turn, causes the quick-acting regulator to act and to bring back the driving motor to the required speed, by a corresponding variation in the voltage of the control set (Ward-Leonard set or booster set).

Fig. 1 shows the switchgear cubicle for a paper-making machine drive of 110 kW rated load, controlled in Ward-Leonard connection; this is a plant delivered to Brazil. The two switchboard panels on the left are for the synchronous motor of the control set which is started up and stopped by push-buttons, by means of contactors and a starting transformer. This arrangement is the simplest method of service imaginable. The synchronous motor plays a big part in improving the power factor of the mill system.

The working speed which happens to be required is set with very fine graduation from the operating side by means of a small apparatus which takes up very little room; to this end, the operator has about 500 setting steps at his disposal. The requisite instruments for service super-

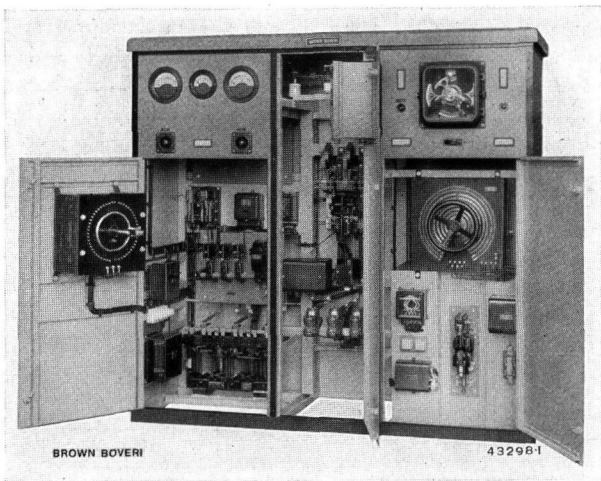


Fig. 1. — Switchgear cubicle for a paper-making machine drive. On the left, two panels for the automatic starting of the synchronous motor of the control set; on the right, the panel for the quick-acting regulating equipment.

vision such as current and voltage meters and a speed-indicating instrument are combined with the said apparatus.

The field rheostat for the Ward-Leonard dynamo, seen in the illustration, is equipped for remote electrical control and has 180 steps, each of which is again subdivided by the quick-acting regulator into a great number of fine intermediate steps. The field rheostat is controlled by the quick-acting regulator, when it reaches its end-travel positions.

Recently, the three-phase shunt commutator motor has been introduced successfully to paper-making machine drives. In cases where a wide range of speed regulation is called for, quick-acting regulation is very recommendable. Fig. 2 shows a drive of this kind. The tachometer dynamo works on a relay built to the quick acting-regulator principle; the latter controls the small motor for brush displacement through a reversing contactor. The relay in question is equipped with a dynamic recall device which,

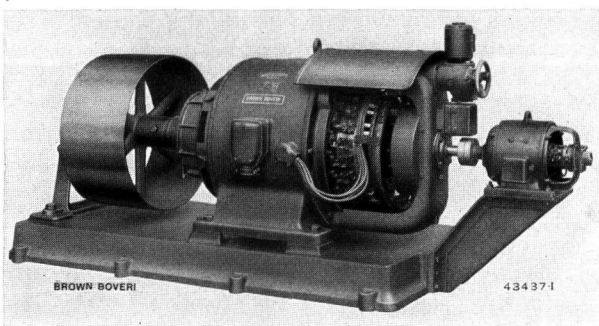


Fig. 2. — Three-phase shunt commutator motor with flanged on gear drive and tachometer dynamo coupled up, for the automatic quick-acting regulation of the speed set to, intended for the drive of a paper-making machine.

combined with certain appropriate measures, prevents over-regulation, and therefore hunting.

For the drives of big high-speed paper-making machines which are all of the electrical sectional type, to-day, it is of great importance that the working speed set to should be maintained with the greatest accuracy. This condition is often the essential factor for attaining working speeds exceeding 300 m/per min. The quick-acting regulation provided to meet these conditions comprises a variant of the standard Brown Boveri quick-acting regulator: — the frequency regulator. The latter assures that the master or pilot frequency remains constant within the very narrow range of  $\pm 0.15$  to  $0.25\%$  and, as the said master frequency is an absolute measure of the working speed, the latter is maintained with great precision, as well.

The switchgear cubicle usually employed for regulating gear of this type is shown in Fig. 3. It is mounted on the operating side of the paper-making machine and contains — apart from the voltmeter and ammeter — an indicating and a recording instrument for the working speed. The latter is set absolutely smoothly (without steps)

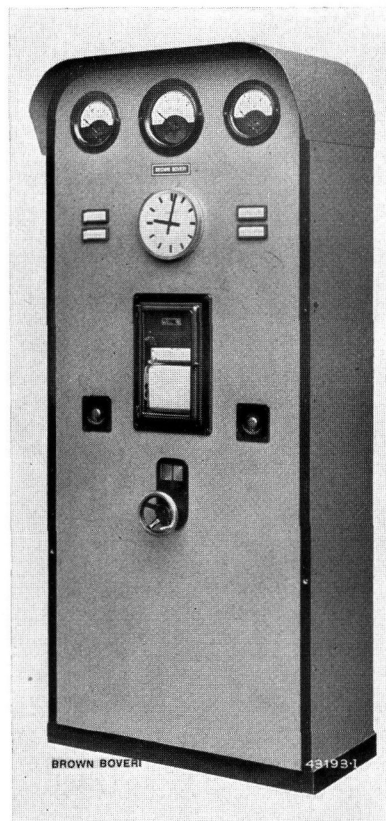


Fig. 3. — Switchgear cubicle for the control of the sectional drive of a paper-making machine, with automatic quick-acting regulation.

by means of the handwheel shown acting through a three-phase movable choke coil.

Brown Boveri has delivered a very large number of quick-acting regulating equipments for paper-making machines, which have given every satisfaction; many of these have been for drives manufactured by other makers. Quick-acting regulation has proved a valuable improvement for drives on account of the severer requirements now made as regards homogeneity of the paper manufactured and as regards rational operation. Every paper-making machine drive to-day should have its quick-acting regulating equipment.

(MS 980)

R. Schnitzer. (Mo.)

### Some new aerial ropeways equipped with Brown Boveri electric drives.

Decimal index 625. 433.

AERIAL ropeways are one of the oldest methods of transport in mountainous regions. The first ones, which were of the simplest design, were used, practically exclusively, for goods traffic. To-day, the number of passengers who may be carried on aerial ropeways, which are operating under concession of a local authority, is limited,



Fig. 1. — Intermediate station on the Nordketten Railway near Innsbruck.

in Switzerland, to four and they are used, chiefly, for local convenience and for carrying winter-sport passengers. A line of this type was built by Robert Aebi Co., in Zurich, to link up Beckenried on the lake of Lucerne and the Klewenalp; it was 3111 m long with a difference of altitude of 1143 m. The travelling speed was 4 m/s and the driving motor a 37-kW three-phase Brown Boveri unit. This ropeway began service with great success in 1933 but the unexpectedly sharp rise in traffic, due to winter-sport passengers, soon proved that the line was quite inadequate to deal with the demand so that, as early as two years after it was built, the decision was taken to make over the ropeway so that the cars could carry 20 passengers each, while so transforming the plant that it met the Swiss Government Traffic Regulations. More details on this new aerial ropeway, for which the electrical equipment was again ordered from Brown Boveri, will be given in a coming number of the Review.

A similar plant was built by the Eisen- und Stahlwerke Oehler & Co., in Aarau, in 1935; this is the Stöckalp-Melchsee-Frutt ropeway, in Central Switzerland. This line carries four passengers per car and serves both the hotel at the higher end and the economic requirements of this alpine region. The ropeway is 3500 m long with a difference of altitude of 826 m; the travelling speed is 4 m/s. The driving plant in the lower station comprises a three-phase induction motor 40 kW, 380 V, 50 cycles, which is regulated by a change-over controller with nine starting positions.

A specially interesting plant is the one built by the firm of Bleichert in Leipzig, for public service, namely the two-section Nordkettenbahn near Innsbruck. The total length of the line is 3632 m, the lower station being at 863 m altitude and the upper one at 2258 m altitude. The drive of both sections of the line is in the intermediate station, at 1906 m altitude. The journey on the lower section takes 12 to 14 minutes at a speed of 3.6–4.0 m/s and 5 minutes on the upper section at 3 m/s. Two cars run in shuttle service on the lower section, each taking 24 passengers while there is only one car on the upper and much shorter line. The electric drives of the two line sections are independent of one another and each has a D. C. main motor of 60 kW continuous rating, in Ward-Leonard connection, with a buffer battery. The power supply, from the Innsbruck Electricity Works, is at 5000 V, 50 cycles which is stepped down in two transformers, each of 125 kVA continuous rating, to 380 V, for

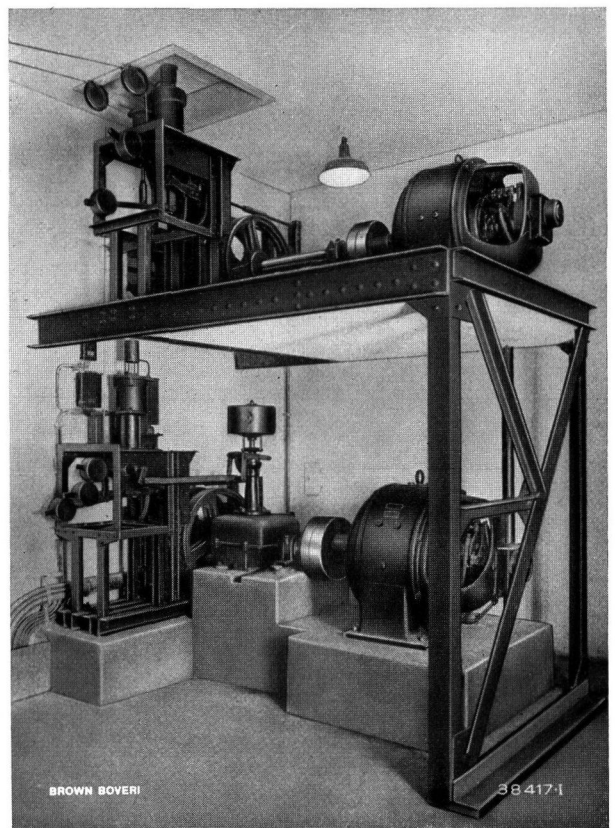


Fig. 2. — Main and auxiliary drives on the Wank Railway.

connecting to the two control sets. These control sets consist of a three-phase induction motor of 70 kW, a D. C. generator of 85 kW and an exciter of 7 kW for the regulation of the generator voltage by means of a change-over controller with 18 switching steps and for the constant independent excitation of the winding motor. There is a buffer machine of 55 kW coupled to the set the duty of which is to get over the load peaks which occur on lines of this nature; this machine gives back superfluous power to a storage battery, it operates automatically as a motor and as a generator according to the service requirements. This solution which was chosen for reasons of power economy allows of having a store of power in reserve if, by any chance, the three-phase current supply should fail. Further, there is a stand-by petrol-electric set of 100 H. P. available to supply D. C. current, the duty of which is to support the buffer battery in its duty of operating the line at ordinary speed, when the three-phase supply is cut out for long periods. Over and above these measures, the line is equipped with the usual safety devices including auxiliary drive for each line section. A whole series of switching possibilities allow of keeping up service under all conditions. The electric equipment was supplied by the Austrian Brown, Boveri Co., in Vienna.

The Obervellach aerial ropeway (Austria) built by the Pohlrig firm on the brake-rope system is a passenger and goods railway. On a length of 1000 m it has a difference of altitude of 360 m and is built for a travelling speed of 4 m/s. Drive is by two D. C. motors each of 45-kW rated load; these are controlled on the Ward-Leonard system, independently of each other.

Another plant, built by the Bleichert firm, Leipzig, with electrical equipment by the Brown, Boveri & Co., Mannheim, is the Wank Railway near Partenkirchen which is 2670 m long. Drive is by a 66-kW D. C. motor in Ward-Leonard connection. There are seven alternatives in case of emergency, namely:— ordinary service with current connection of main drive to the supply system through the control set, power supply by two Diesel-electric stand-by sets for full traffic-capacity conditions or else supply by one of the said sets for a lower travelling speed. The first and the second-last working conditions can also be used with the auxiliary drive. Under ordinary conditions, the power supply is A. C. single-phase, 2000 V, 60 cycles.

Apart from the plants just mentioned which are equipped in Ward-Leonard connection, according to the regulations in force in the countries in which they are situated, mention should be made of the Sestrières and Banchetta lines built by the firm of Bleichert in Leipzig. The first of these is in two sections, each 902 m long, the total difference in altitude being 562 m, while the second is in one section 2730 m long with a difference of altitude of 517 m. The electric equipment was delivered by Tecnomasio Italiano Brown Boveri, Milan, and consists of two three-phase motors of 80 kW and 41 kW for the main drive of the first plant and of 92 kW for the second plant, at 220 V supply voltage, 50 cycles. The travelling speed is 4 and 2 m/s for the Sestrières line and 5 m/s for the Banchetta line. A detailed description

of similar plants and of the safety devices generally used in aerial ropeways will be found in the Brown Boveri Review of the year 1926 and 1928 in which the Italian Merano-Avelengo and Oropa-Mucroneese plants are described.

The Wetterhorn lift near Grindelwald, which started operations in the year 1908, should be of historical interest. This lift equipped by the von Roll Iron Works in Berne, and having electrical equipment by Brown Boveri, was used for tourist traffic only. It had a carrying capacity of 16 passengers per cage and the distance travelled over was 530 m with a difference of altitude of 405 m; the

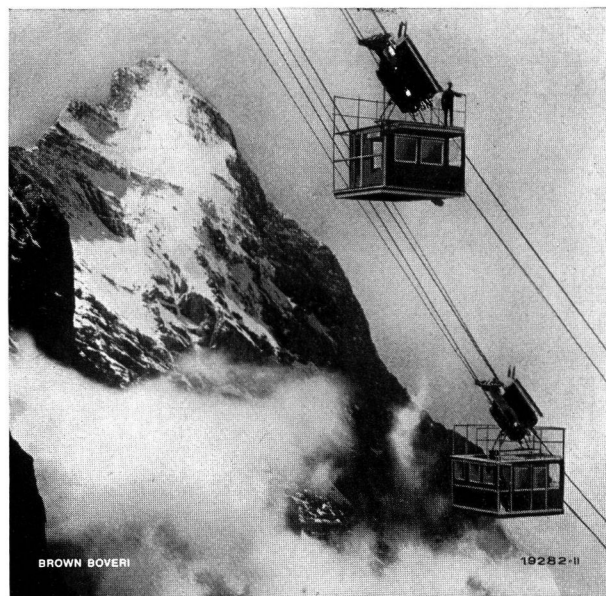


Fig. 3. — Wetterhorn lift.

speed of the lift was 1.5 m/s the grade being 61 to 206%. Drive was by a D. C. shunt motor, of 52 kW at 750 r. p. m. and 800 V terminal voltage, connected to a single-phase 2500 V supply at 46 cycles through a cascade converter. This, the first Swiss aerial ropeway, which was dismantled a short time ago, as it was running at a loss, furnished valuable constructive data and experience in service which came in very useful for more recent plants.

To summarize, it should be said of the 50 important passenger-carrying aerial ropeways, in public service in Europe, more than a quarter are electrically equipped by Brown Boveri. This equipment is always of a type best suited to the characteristics of the line served and meets every requirement as regards safety in service, overloading capacity and little maintenance, all conditions which are demanded of the equipments of lines of this type.

(MS 959)

E. Hugentobler. (Mo.)

#### Small power stations in South America.

Decimal index 621.311.2 (8).

THE following is a short description of some small power stations which Brown Boveri delivered to South American countries in the course of last year and which have been started up, recently.

1. *Diesel-electric power station Junta de Beneficiencia de Tumaco Narino district, Columbia.* A power station equipped with two Diesel-electric sets, having three-phase A. C. generators, each built for 100 kVA, 500 V, 60 cycles, 450 r.p.m., was put up in Tumaco, one of the Columbian harbour towns on an island on the west coast of South America. A wall-type of switchboard with three panels contains the 500-V switching and measuring equipment for the two generators as well as the apparatus on the low-voltage side of a 200-kVA transformer for stepping up the generator voltage to 2400 V.

As the plant is in close proximity to the sea shore, all iron parts are subjected to the deleterious effect of salt sea air. For this reason, all iron parts of the plant had to be galvanized and the apparatus made as air-tight as possible.

Further, four substations were put up and a high and low voltage system laid out which covers the whole island.

2. *Hydro-electric plant belonging to Mr. Fernando Perez Pallares, Ipiales, Columbia.* This plant is in the southern part of Columbia, situated in a high valley of the Andes mountains, at 3000 m altitude above sea level. It takes the place of another older plant, and is created by prolonging the existing penstock downwards, which

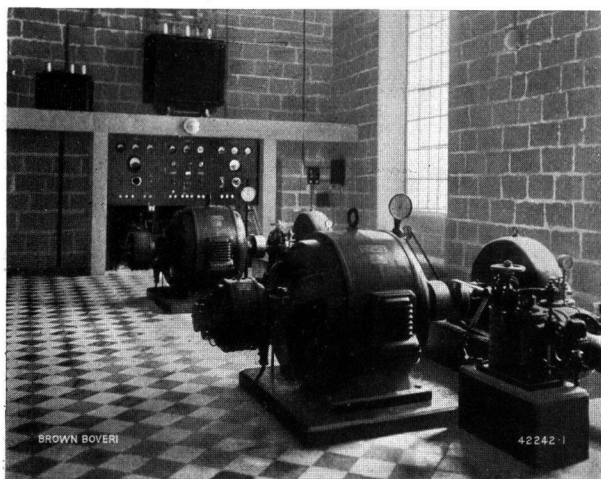


Fig. 1. — The small power station Las Lajas (South Columbia) with wall-type switchboard and transformers.

gives a head of water double the original one. There are two generating sets in the station with Pelton-wheel turbines direct-coupled to generators 144 kVA, 500 V, 60 cycles, 900 r. p. m. Fig. 1 shows the two sets and, in the background, the wall-type of switchboard as well as the power and station transformers.

The total load of the plant is led to a substation, for which Brown Boveri also supplied the electric material. The power generated supplies light and power to a textile mill and to the town of Ipiales.

3. *Diesel-electric power station of the industrial enterprises "Cima" in Manta, Ecuador.* This station supplies current to different industrial plants and also lights the

town of Manta and its harbour. This is a Diesel-electric plant which, for the time being, has only a single set producing 135 kVA, three-phase A. C. current, 380 V, 60 cycles, 360 r. p. m. the voltage being stepped up in a transformer to 2400 V. Later on, it is intended to double the output by putting in a second generating set.

4. *Hydro-electric plant in Huigra, Ecuador.* This is a high-head hydro-electric station with a three-phase generator 60 kVA, 380/220 V, 60 cycles, 1200 r. p. m. direct-coupled to a Pelton-wheel turbine. Later, it is intended to put in a second generating set. This plant supplies the locality of Huigra with light and power. The electric equipment for three substations was also delivered by Brown Boveri.

5. *Thermal-electric power station Cervecería Ciudad Bolívar, Venezuela.* This beer brewery, a subsidiary of the *Compañía Anónima Cervecería de Caracas*, gave Brown Boveri the order for the electrification of the whole brewery plant including a power station which comprises the two following sets:—

1 three-phase A. C. generator, 114 kVA, 230 V, 60 cycles, 1200 r. p. m. driven by a gas engine of 140 H.P. through a Brown Boveri spur-wheel gear with roller bearings and dip lubrication.

1 three-phase A. C. generator, 24 kVA, 230 V, 60 cycles, 1200 r. p. m. belt-driven from a steam engine.

The second set is, chiefly, a stand-by. The switching and measuring apparatus for both generators and for the distribution is lodged in a three-panel switchboard. The material delivered includes 12 driving motors with corresponding battery of switchboxes and a centrifugal pump.

6. *Diesel-electric plant for the Compañía Aurífera Nazca, Peru.* This electric plant comprises four generating sets, with each one three-phase A. C. generator, 122 kVA, 230 V, 60 cycles, 300 r.p.m.; it was started up quite recently. Power distribution is at low voltage, here. The current is used to supply power and light to a gold mine. The switching and measuring equipment and the different outgoing leads are lodged in an eight-panel switchboard.

(MS 986)

W. Kissling. (Mo.)

#### Service reliability of Brown Boveri material.

Decimal index 6 (009.2): 621. 314. 21.

READERS will be interested to hear that, apart from certain rotary machines already mentioned under the above heading, there are transformers operating to-day which have been in service for remarkably long periods without requiring any repairs whatever.

The Electricity Works of the Canton of Thurgau, situated in Arbon, have a whole series of Brown Boveri transformers on their system which have been in continuous operation for more than thirty years. Up to date, not the slightest repair has been called for on these units. These are transformers of 20 to 80 kVA ratings, 8000/350/200 V and 8000/250/144 V, 50 cycles, with workshop numbers between 6434 and 8431, that is to say, belonging to a series of products built in early days.

(MS 979)

Prop.